The Influence of Lead Selection on the Correlation Dimension for Quantification of the Chaotic Attractor Underlying Polymorphic Tachyarrhythmias

WRM Dassen, RGA Mulleneers, EO Postma*, WA Dijk#, J Haaksma#, S C Verduyn, M A Vos

Depts. of Cardiology and Computer Science*, Univ. of Limburg and Groningen#, Maastricht/Groningen, Netherlands

Abstract

Currently the correlation dimension is frequently used to quantify the non-linear properties of the electrocardiogram recorded in rest or during various tachyarrhythmias. In this study the influence of lead selection and embedding dimension on the correlation dimension was evaluated. In nine dogs presenting with Torsade de Pointes tachyarrhythmias the correlation dimension was determined using the commonly applied method of Grassberger and Procaccis, for the embedding dimension 3,4,5 and 8. Between dogs the average correlation dimension varied from 1.37-2.12, 1.42-2.39, 1.45-2.63, and 1.55-3.03 respectively. Within dogs the difference between those two leads with the minimal and maximal dimension varied from 0.17-0.67, 0.19-0.95, 0.24-1.00 and 0.32-1.14 .

The study suggests that the correlation dimension should not be used to compare the non-linearity between patients but should be limited to longitudinal comparison in one patient.

1. Introduction

Recently risk-stratification based on parameters derived from the electrocardiogram, using methods from non-linear analysis like the estimated correlation dimension, is rapidly gaining interest (1-7). In most of these studies an arbitrarily selected electrocardiographic lead is used. In the majority of cases no statement is presented why a specific lead has been selected.

2. Purpose of this study

To evaluate the potential influence of lead selection on the correlation dimension, using the commonly applied method of Grassberger and Procaccia (8), the experiment described in this paper was performed.

3. Methods

3.1. Animals

In nine anesthetized dogs, in which in a laboratory setting reproducible self-terminating Torsade de Pointes tachyarrhythmias could be initiated by a programmed electrical stimulation protocol, the six standard electrocardiographic extremity leads were recorded, digitized at a sampling rate of 1000 samples/sec and stored on hard disk. During analysis of these tracings the electrocardiogram and intracardiac registrations of all relevant episodes were annotated and collected on CD-ROM. Off-line, apart from the normal electrophysiological analysis, a number of additional parameters, including the correlation dimension was estimated using 4000 samples, various embedding dimensions and an individualized reconstruction delay.

3.2. MTRCHAOS

All analyses were performed using the MTRCHAOS and MTRLYAP software packages. These software tools can be downloaded from the Internet network (9). The analysis of nine electrocardiograms, each recorded with 6 leads, and four different embedding dimensions resulted in 216 different experiments. In this study for each experiment the optimal setting was determined, applying a number of options available in this package.
In each experiment 4000 samples were analyzed, with an embedding dimension of 3, 4, 5 and 8. To calculate the estimated correlation dimension a number of parameters have to be selected. The optimal reconstruction delay, the mean interval and the number of sampling intervals the divergence pattern of a given pair of nearest neighbors should be followed, were individually determined in each experiment.

3.2.1. Reconstruction delay

The estimation of the optimal reconstruction delay can be guided by three methods: the average displacement, the autocorrelation method or the so-called small window solution. As published by Rosenbaum, a measurement of reconstruction expansion and therefore an indication of the effect of the measurement error as a function of the delay selected can be provided by the average displacement. Empirical results suggest an optimal estimation of the reconstruction delay as that delay where the slope first drops to 40 % of the initial value (9,10). The autocorrrelation method although frequently used to select the optimal delay, and the small-window solution described by Gibson have not been applied in the experiments described in this study.

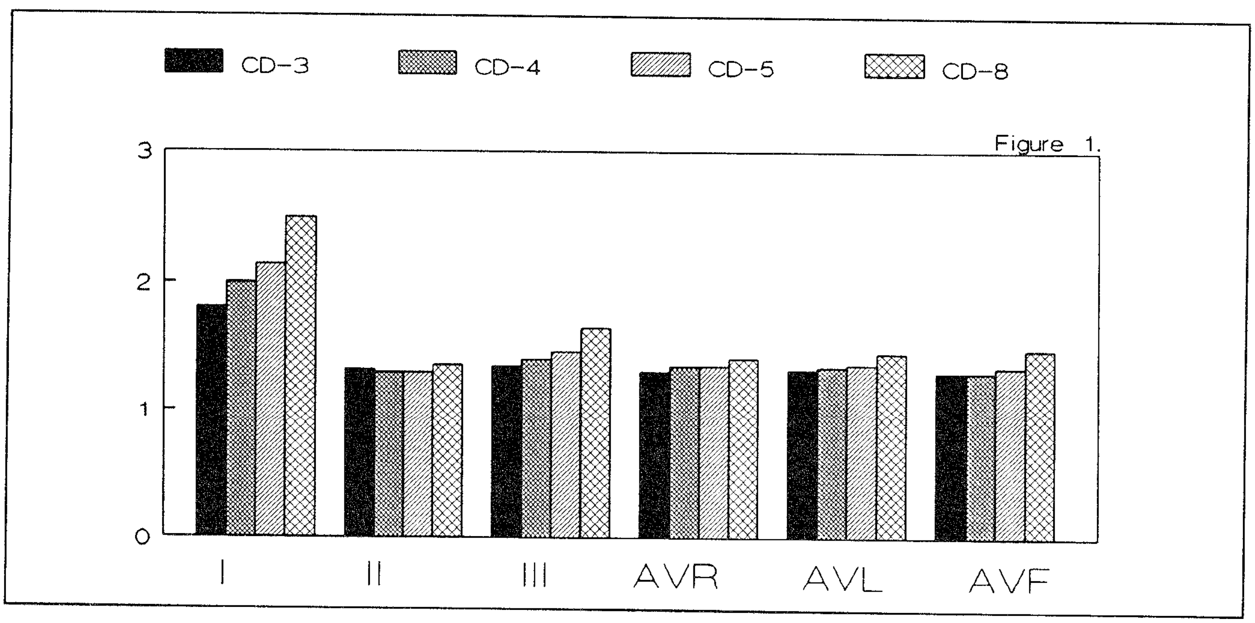
4. Results

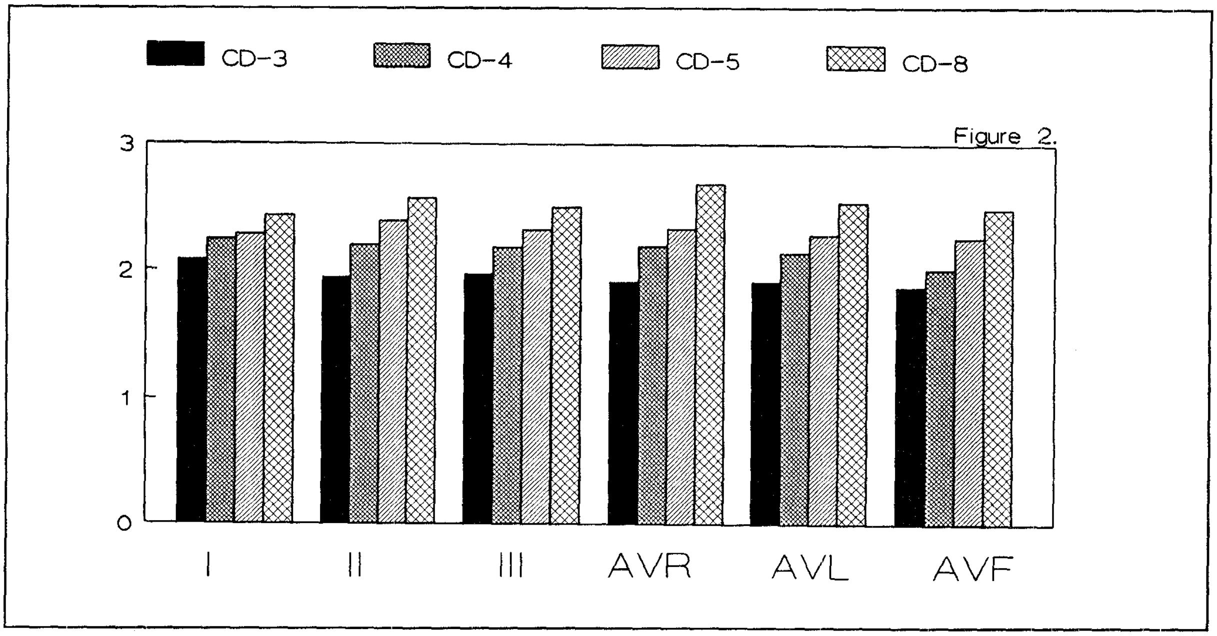
Between dogs the average estimated correlation dimension calculated on these 6 extremity leads for four embedding dimensions varied from 1.37-2.12, 1.42-2.39, 1.45-2.63, and 1.55-3.03 respectively. Within dogs the difference between those two leads with the minimal and maximal dimension varied from 0.17-0.67, 0.19-0.95, 0.24-1.00 and 0.32-1.14 .
Table 1. lists the maximal difference found for all nine animals and four embedding dimensions.
The differences found could not be explained by the inaccuracy introduced by the manual selection of the linear part of the correlation diagram, as required in the method of Grassberger and Procaccia.

TABLE 1.
Delta correlation dimension for embedding dimension

		3	4	5	8
Dog	1	0.17	0.19	0.24	0.32
	2	0.51	0.70	0.84	1.14
	3	0.21	0.23	0.13	0.26
	4	0.67	0.95	1.00	0.94
	5	0.51	0.60	0.65	0.89
	6	0.36	0.48	0.47	0.59
	7	0.65	0.80	0.90	1.12
	8	0.58	0.62	0.70	0.74
	9	0.34	0.55	0.55	0.93

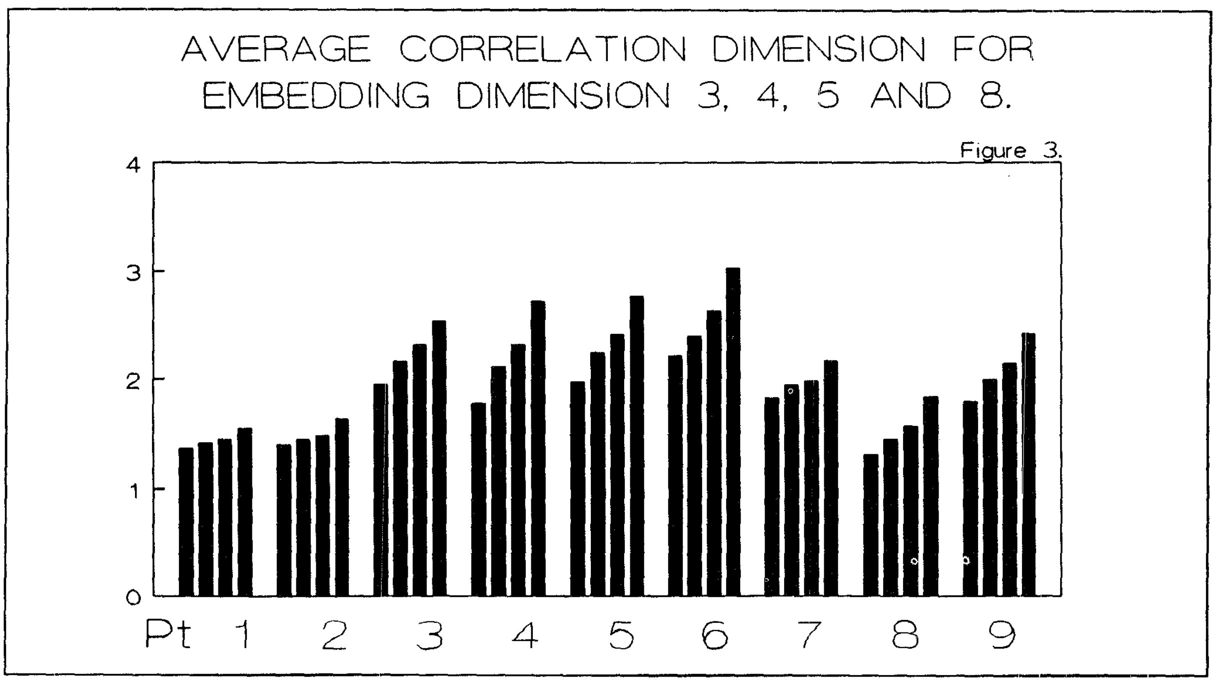
The electrocardiogram did not reveal any clues why some leads did behave so differently as compared to other ones. The correlation dimension in relation to the embedding dimension calculated for six leads showed a large variation of patterns. In some cases a pattern is seen in which the correlation dimension is almost constant for different embedding dimensions in five out of six leads, and totally different in a sixth lead. An example of this pattern is given in figure 1.





In other cases an increase of the correlation dimension was observed while expanding the embedding dimension but to an extent equal in the different leads, as illustrated in figure 2.

The average correlation dimension for the four different embedding dimensions used in these experiments, calculated over all six extremity leads, is illustrated in figure 3.



5. Conclusion

Whether the by definition extreme polymorphic nature of Torsade de Pointes tachyarrhythmias is mainly responsible for the unexpected large variation in estimated correlation dimension, or this irregularity in combination with the selected sampling frequency and number of samples used in this analysis, deserves further investigation. In the mean time, however, these results do support the judgment, that the estimated correlation dimension should not be used to compare the chaotic properties of the electrocardiogram between patients, but should be limited to longitudinal comparison of the electrocardiogram in a patient without varying variables like embedding dimension, reconstruction delay and electrocardiographic lead selection.

References

[1] Chaos and the ECG: fact and fiction. Albert DE. J Electrocardiol 1991;24S: 102-106.

[2] Denton T, Diamond G, Helfant R, Khan S, Karagueuzian H. Fascinating rhythm: a primer on chaos theory and its application to cardiology. Am. Heart J 1990;120: 1419-1440.

[3] Skinner JE,Carpeggiani C, Landisman CE, Fulton KW. Correlation dimension of heart beat intervals is reduced in conscious pigs by myocardial ischemia. Circ res 1991;68: 966-976.

[4] Kanters JK, Holstein-Rathlou N-H,Anger E. Lack of evidence for low-dimensional chaos in heart rate variability. J Cardiovasc Electrophysiol 1994;5: 591-601.

[5] Glass L. Is cardiac chaos normal or abnormal. J Cardiovasc Electrophys 1990;1: 481-482.

[6] Stein KM, Lippman N, Kligfield P. Fractal rhythms of the heart. J Electrocardiol 1991;24S: 72-76.

[7] Can the technique of nonlinear dynamics detect chaotic behavior in electrocardiographic signals? Denton TA, Diamond G, Khan S, Karagueuzian H. J Electrocardiol 1991;24S: 85-90.

[8] Grassberger P, Procaccia I. Measuring the strangeness of strange attractors. Physica D 1983;9: 189-208.

[9] HTTP://members.aol.com/MTRw3/w3/sw/sw00.html#MTR.CHAOS

[10] MT Rosenstein JJ, Collins and CJ de Luca. Reconstruction expansion as a geometry-based framework for choosing proper delay times. Physica D 1994; 73: 82-98.

Address for correspondence:

Willem RM Dassen,PhD
Dept.of Cardiology, University of Limburg,
POBox 5800, 6201 AZ Maastricht, Netherlands.
Tel xx31 43 3877090
Fax xx31 43 3875104
E-mail w.dassen@cardio.azm.nl